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Field Survey of Air Conditioner Temperature Settings in a Hot, Dry Climate (Oman)

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ABSTRACT

In conventional air conditioning design, the comfortable range of temperatures is 25 to 27°C, with relative humidity levels of 40 to 60%; these numbers vary only slightly based on a person's race and country. Several studies in tropical climates show that the observed thermal comfort requirement often does not agree with those obtained based on experiments mainly using North American subjects. However, there is no consistent rationale that explains why the comfort requirements are different in a hot climate, suggesting more surveys on thermal comfort may be needed in the tropics.

In Asia, there has recently been a rapid and widespread diffusion of air conditioners. Therefore, we conducted a survey to clarify what temperature and humidity level people in Asian countries prefer in order to feel comfortable. Following that research, this article presents the results of a questionnaire survey on the use of air conditioners in houses in hot, dry climates.

Nizwa and Rustak, Oman, which are characterized by the hot, arid climate of the Arabian Peninsula, were chosen as survey areas. The questionnaire survey was distributed to students of Nizwa University. Questions were asked about the duration of air conditioner use and the preferred air conditioner temperature setting. In order to determine how respondents felt about their indoor environment, we also asked about the thermal sensations that were experienced while using the air conditioner. In both cities, the mean operating time of the air conditioner was very long. The respondents reported selecting a low temperature setting while sleeping despite the fact that many of them reported that they were cold while sleeping. Ninety percent of respondents reported a cold, cool, or neutral thermal sensation while using the air conditioner, without feeling discomfort.

1. INTRODUCTION

In conventional air conditioning design, the comfortable range of temperatures is 25 to 27°C, with relative humidity (RH) levels of 40 to 60% (ASHRAE 2005); these numbers vary only slightly based on a person's race and country (Fanger 1970). However, the authors have frequently experienced conference halls and hotels in Indonesia and Singapore that are maintained at very low temperatures, which seems inconsistent with these research results. Fanger has proposed a predicted mean vote (PMV), based on the comfort equation and predicted percentage of dissatisfaction (PPD) on which the international thermal comfort standard ISO7730 is based. Although the comfort equation is based on experiments using North American subjects, the application of the equation to other groups has been discussed. Several studies on thermal comfort in tropical climates have been conducted (Busch 1992; Nicol 1973, 2004; Sharma et al. 1986), and these studies

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show that the observed thermal comfort requirement in hot climates is not in firm agreement with that dictated by the thermal comfort equation. However, there is no reasonable and consistent rationale that explains why the comfort equation does not adequately describe comfortable conditions in a hot climate. On the other hand, de Dear et al. (1991) conducted an experiment in Singapore in which climate chamber subjects adjusted the temperature according to their wishes. At the observed preferred temperature, the mean thermal sensation was significantly lower than neutral, which indicates that subjects prefer cool conditions. International thermal comfort standards define the neutral temperature obtained from physical measurement and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) thermal sensation scale as a measure of comfort. However, as these field studies show, more surveys on thermal comfort may be needed in different climatic regions such as the tropics.

In Asia, which is generally a hot and humid climate region, people are somewhat used to controlling their indoor thermal environment by using external air flow (Kubota et al. 2006), and most researchers have focused on the cooling effect of natural ventilation. However, there has recently been a rapid and widespread diffusion of air conditioners (Ministry of Internal Affairs and Communications. 2002). Thus, people seem to prefer a cool indoor environment (Uno et al. 2003). Therefore, we conducted a survey to clarify what temperature and humidity level people in these regions prefer in order to feel comfortable, using a questionnaire survey and measurements of indoor thermal environments (Nastiti et al. 2013). Following that research, this paper presents the results of a questionnaire survey on the use of air conditioners in houses in hot, dry climates. The objective of the survey was to clarify what temperature and humidity levels people in hot, dry regions prefer in order to feel comfortable, with a special focus on their sleeping environment.

2. OUTLINE OF SURVEY

2.1 Studied area

Two cities in Oman, Nizwa (N23°E57°) and Rustak (N22°E57°), which are characterized by a hot and arid climate, were chosen as the survey areas. The annual variations in air temperature, and relative humidity in the two cities are shown in Figures 1 and 2, along with those of Tokyo (Data from World Organization 2002). From April to October, the monthly mean air temperatures are over 30°C, and the daily highest temperature reaches 40°C in July. The daily amount of solar radiation ranges from 14 to 22 MJ/m²/day (Figure 3). Conversely, the daily lowest temperature in January is nearly 10°C. There is a small amount of precipitation throughout the year, from 0.5 to 19 mm/month (Figure 4).

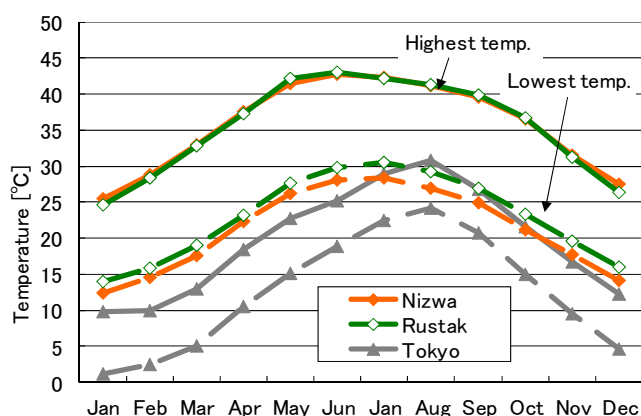


Figure 1. Outdoor temperature of Nizwa and Rustak.

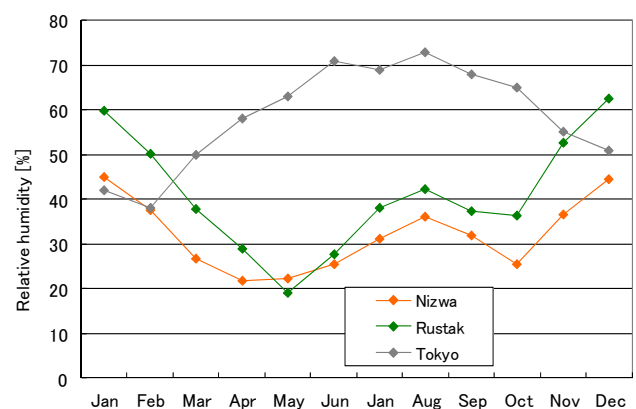


Figure 2. Relative humidity of Nizwa and Rustak.

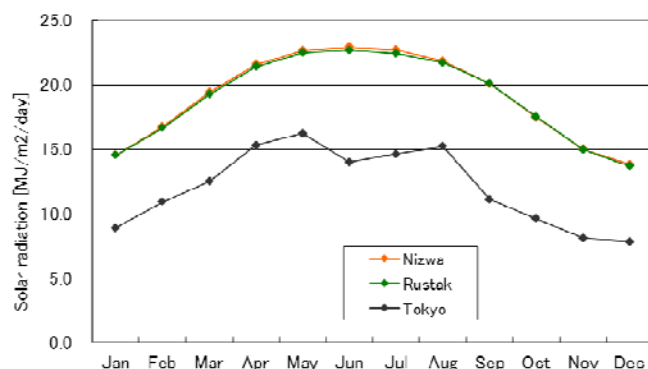


Figure 3. Solar radiation of Nizwa and Rustak.

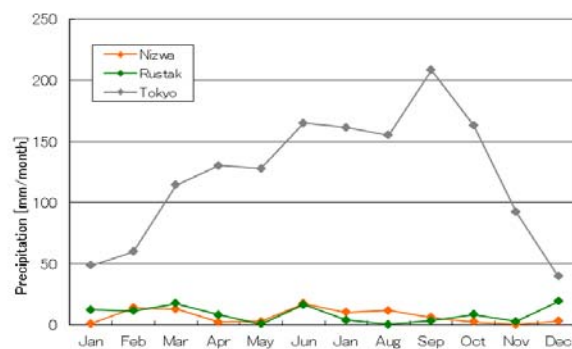


Figure 4. Monthly precipitation of Nizwa and Rustak.

2.2 Respondents and period of survey

Residential buildings were chosen for the survey instead of non-residential buildings because the occupants have a greater chance of being able to choose their preferred temperature setting for the air conditioner. Conference halls and hotel lobbies are designed for public use, so some of the occupants may have to endure conditions that are set to accommodate the comfort level of the average person. Therefore, in order to achieve the authors' objectives, measurements in residential buildings and responses from their residents were used in this research.

The questionnaire survey was given to 87 students in the Architectural Department of Nizwa University. The survey was carried out three times: in the first quarter of 2010, in June 2011, and in October 2011. Table 1 shows the time of the survey, number of respondents, and questionnaire items. These surveys were handed out during class, and the students were directed to fill them out at home in both cities. They were then collected in a later class.

Table 1. Questionnaire for Residents

No. of Survey	Survey Period	Number of Reports	Questionnaire Items
First time	Jan. ~ Mar., 2010	22 (Nizwa)	<ul style="list-style-type: none"> ■ About your home <ul style="list-style-type: none"> Your family, Type of house, Number of stories, Structure of house, Electric appliances, Plan of house, Users of the bedroom, Opening and closing of windows, Electricity charge, Clothing during sleep, Annual income
Second time	June 2011	12 (Nizwa), 14 (Rustak)	<ul style="list-style-type: none"> ■ Use of air-conditioners (AC) <ul style="list-style-type: none"> Manufacturer and price, Usage time of AC, Set point temperature of AC, Health, Necessity of AC, Electricity use, Economic effects of using AC, Countermeasures when cold in the bedroom, thermal environment in the bedroom during normal use of an AC (set-point temperature, thermal sensation, comfort sensation, more favorable environment)
Third time	October 2011	39 (Rustak)	

2.3 Questionnaire items

In order to comprehensively understand the circumstances surrounding the use of air conditioning in these cities, the questionnaire items included not only the use of an air conditioner but also information about living conditions. For

example, the questions regarding living conditions asked about the number of family members, house layout, house construction, surrounding environment, income, and electrical appliances owned by the household. Questions concerning the use of air conditioners asked about the duration of air conditioner use and the air conditioner temperature setting. The first questionnaire results revealed that most respondents used an air conditioner for a long time while sleeping. Therefore, to determine how the respondents felt about their indoor thermal environment while using an air conditioner, the authors also asked about the thermal sensations that they experienced while using the air conditioner, the clothing worn while sleeping, and any health problems reported while using the air conditioner. Further details are given in the appendix.

3. RESULTS OF SURVEY

3.1 Results of living conditions

a) Family members. The average household size was 6.7 persons among the Nizwa respondents and 7.2 persons among the Rustak respondents. More than 90% of people live in a detached house called a “villa” or apartment house.

b) Monthly household income and electricity charges. Figure 5 shows the monthly household incomes of the respondents’ families. Among the respondents in both cities, about 50% of families had a monthly income of less than 10,000 OMR (25,000 USD, 1USD=0.385OMR), whereas 10 to 20% of families had incomes of 40,000 OMR or more.

Figure 6 shows the monthly electricity charges for the respondents. In both cities, more than 70% of families had monthly electricity charges of less than 100 OMR. The mean monthly electricity charge is 70 OMR in Nizwa and 68 OMR in Rustak. In Oman, the subsidiary for energy use is paid by the government, and the electricity charge for kWh is about 0.011OMR/kWh for the use of up 3,000 kWh. Therefore, the net consumption of electricity is significant, although the electricity charges are not particularly high.

c) Number of air conditioners. The air conditioners owned per family was 5.9 in Nizwa, 6.9 in Rustak, and 2.5 in Japan. Figure 7 shows the room where the air conditioner was installed. In particular, the installation rate in bedrooms is very high in both cities in Oman, almost 100%, which means great value is placed on the thermal environment during sleep. In the living room, the guest room, and the kitchen, the installation rates are higher than 60%. From these high installation rates, it is clear that having air conditioning has become a priority for many citizens.

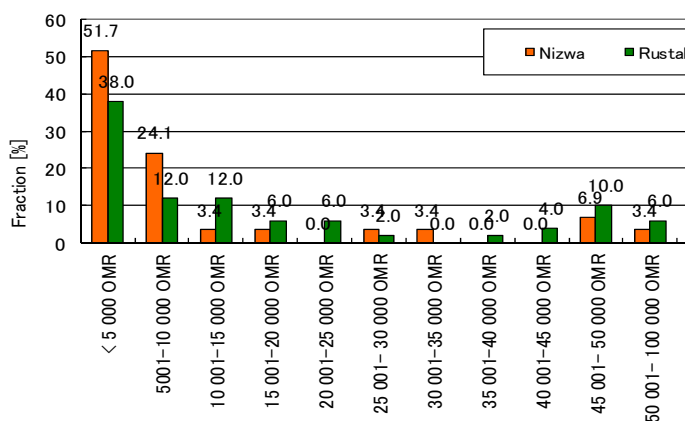


Figure 5. Monthly household income.

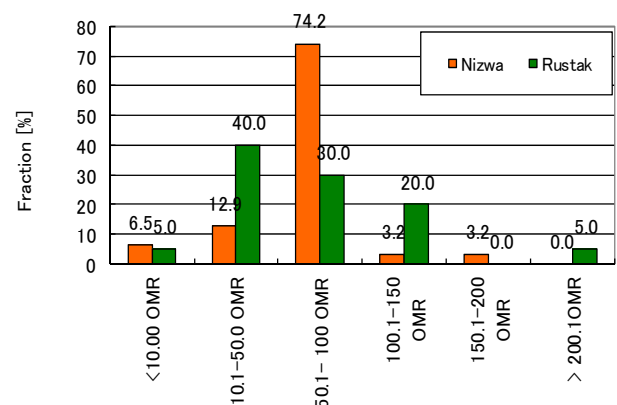


Figure 6. Monthly electricity charges.

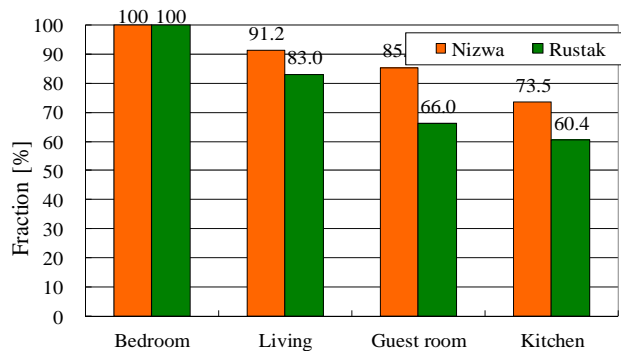


Figure 7. Room where air conditioner was installed.

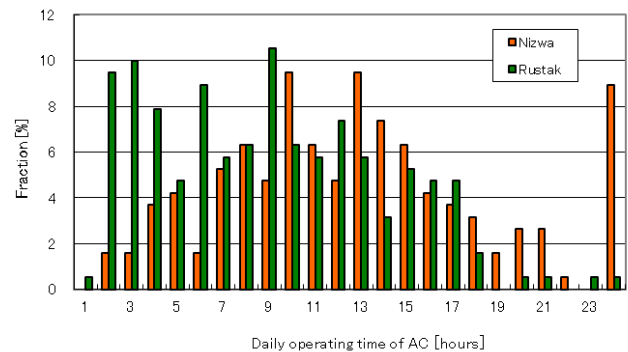


Figure 8. Daily operating time of air conditioner (hours)

The following items were answered by each user with an air conditioner in their bedroom (107 respondents in total in Nizwa and 195 in Rustak).

d) Operating time of air conditioners. Figure 8 shows the daily operating times of air conditioners. The longest period of use was 24 hours in both cities (9% in Nizwa); the average use was 12.8 hours in Nizwa and 9.1 hours in Rustak.

e) Temperature settings of air conditioners. Figure 9 shows the temperature settings of the respondents' air conditioners. There are two peaks, one centered at around 18°C and the other centered at 25°C in Nizwa, while more than half the people in Rustak set it lower than 20°C. The average temperature settings were 21.6°C in Nizwa and 19.7°C in Rustak. These values are rather low for environmental temperature settings for sleeping.

f) Thermal sensations while sleeping. Figure 10 shows the thermal sensations the respondents reported while sleeping. Surveys on thermal sensations usually use votes based on the ASHRAE seven-point scale. However, in this survey, the respondents were asked to rate the thermal sensation based on a five-point scale ranging from cold (1) to hot (5), with neutral (3) in the middle for ease of response.

While sleeping, 68% of respondents in Nizwa and 65% in Rustak reported thermal sensations of 1 or 2 (2=cool); votes of 1, 2, and 3 accounted for 88% and 95% of the total votes in Nizwa and Rustak, respectively. The most common level of sensation among the Nizwa respondents was 2 (37%), whereas it was 1 (41%) for the Rustak respondents, and more people chose 1 than 3 (neutral). The averages were 1.5 in Nizwa and 2.1 in Rustak. The air conditioners were set to temperatures that created cold or cool thermal sensations.

g) Comfort sensations. The percentage of respondents who reported a “very comfortable” comfort sensation was the highest in both cities, 46% in Nizwa and 51% in Rustak (Fig. 11).

h) Favorable environment. Figure 12 shows the favorable environments. In Nizwa, the respondents reported “as it is” (70%), “cooler” (18%), then “warmer” (12%), respectively. In Rustak, “cooler” and “as it is” had almost the same number of respondents. Favoring a “warmer” environment had the lowest percentage of respondents (~10%) in both cities.

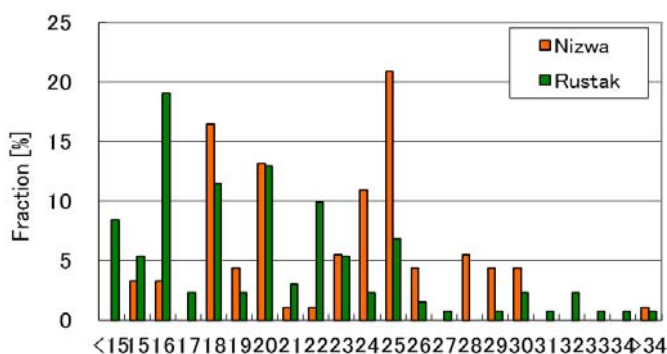


Figure 9. Set-point temperature of air conditioner.

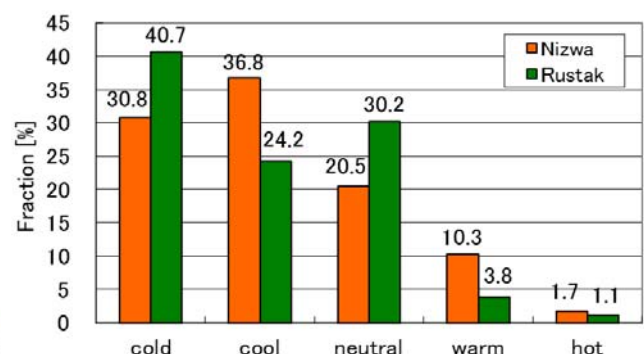


Figure 10. Thermal sensation during sleep.

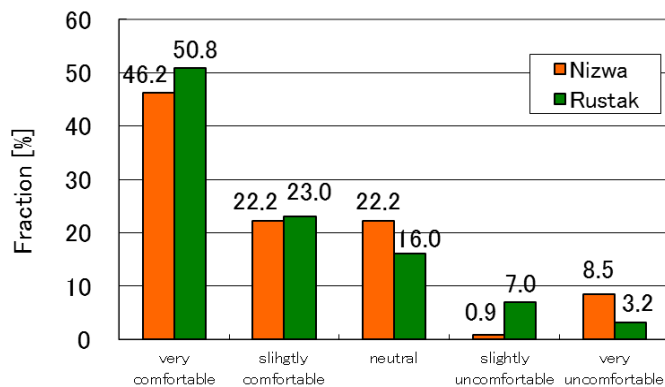


Figure 11. Comfort sensation.

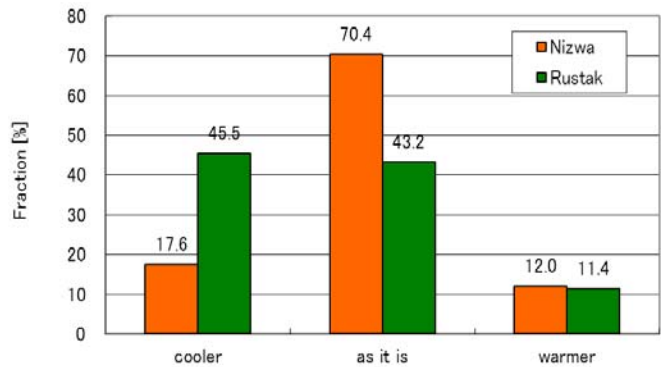


Figure 12. Favorable environment.

i) Health problems. Although the majority of respondents in both cities reported having no health problems, about half (43.8%) of the respondents in Nizwa and 38.5% of respondents in Rustak complained of some health problems while staying in an air-conditioned room (Figure 13). It seems clear that these health problems were partly related to using air conditioners set at low temperatures.

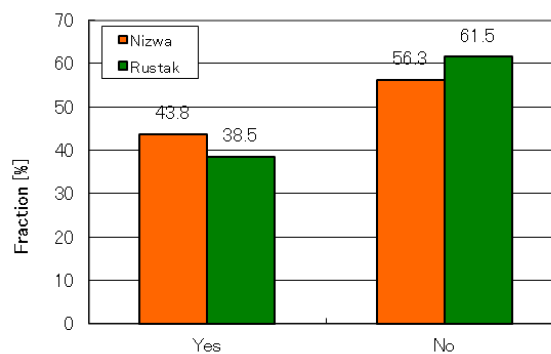


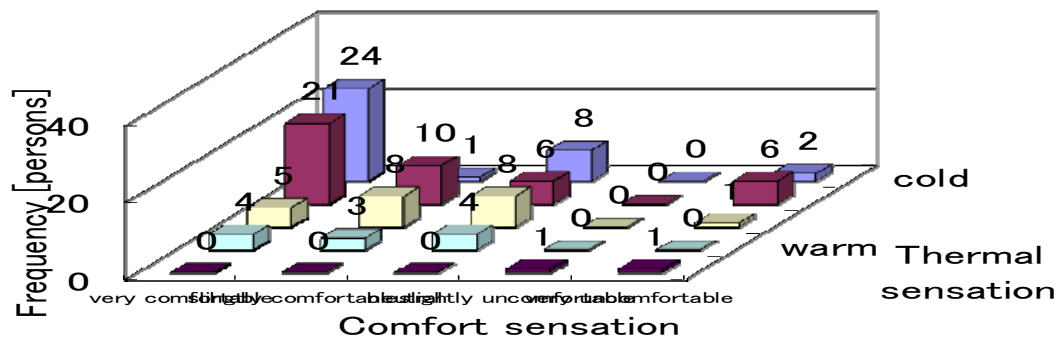
Figure 13. Percentage of health problems reported by survey participants.

3.2 Thermal and comfort sensations

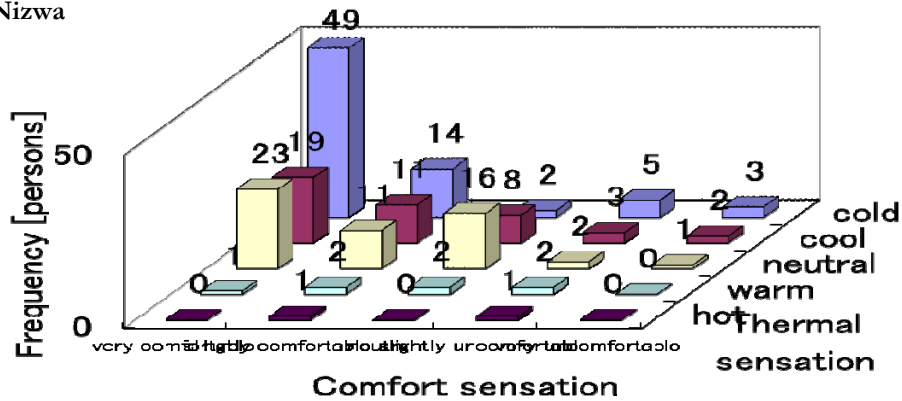
Figure 14 shows the breakdown of comfort sensations within each thermal sensation. The numbers shown indicate the number of respondents who reported a specific sensation. In both cities, the number of residents who reported having a “cold” or “cool” thermal sensation and a “very comfortable” or “comfortable” comfort sensation was quite high. The percentage was 55% for Nizwa respondents and 53% for Rustak respondents.

Thus, most respondents did not consider being cool or cold as negative. On the other hand, fewer people reported having a “neutral” thermal sensation and being very comfortable or comfortable than reported having a cold or cool thermal sensation and being very comfortable or comfortable. Thus, the respondents tended to feel more comfortable in cold or cool environments than in neutral environments.

Figure 15 shows the breakdown of favorable environments for each thermal sensation. Many respondents desired a cooler environment regardless of the thermal sensation they experienced, particularly in Rustak. Interestingly, among people who reported being cold or cool, 25% of respondents in Nizwa and about 50% of respondents in Rustak wanted a “cooler” environment, which was much higher than the number of respondents who wanted a “warmer” environment. It is clear that people who reported both a cold thermal sensation and a desire for a cooler environment do not regard the sensation of being cold as uncomfortable.

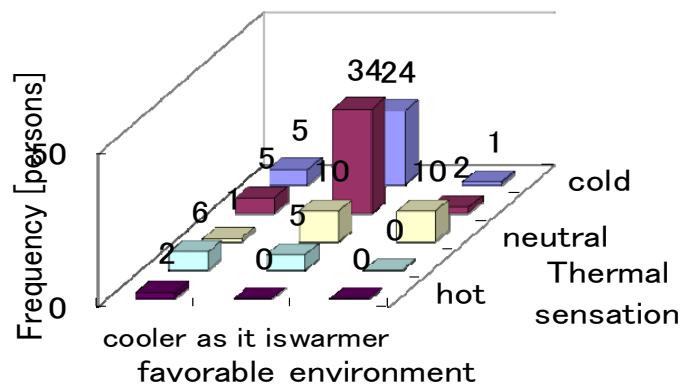


A) Nizwa

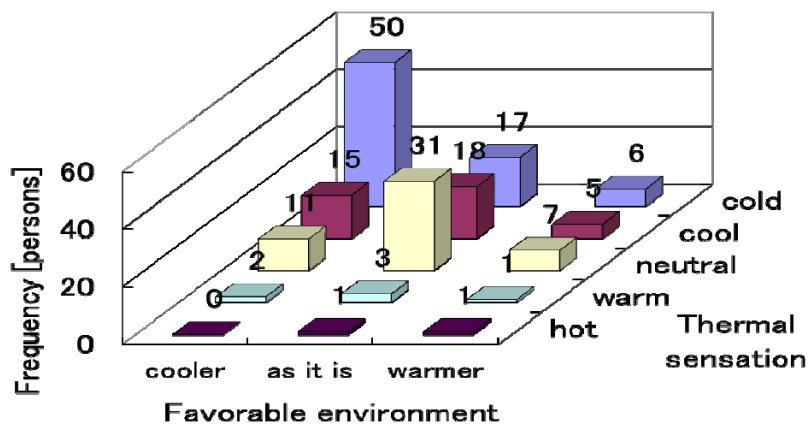


B) Rustak

Figure 14. Breakdown of sensation of comfort in each thermal sensation



A) Nizwa



B) Rustak

Figure 15. Breakdown of favorable environment in each thermal sensation

4. MEASUREMENT OF INDOOR THERMAL ENVIRONMENT

4.1 Outline of measurement

In order to understand the relationship between the indoor thermal environment and thermal sensations, we measured the indoor air temperature and RH levels. In this section, a part of the measured results is shown that was obtained in four residential buildings in Nizwa for November 20 to 22, 2011. The temperature and humidity were measured in the living- and bedrooms of each house using handy-type hygro-thermometers.

4.2 Measured results

a) Residence A (Figure 16): In the bedroom, the air conditioner was operated with the highest intensity mode from 9:30 P.M. to 6:00 A.M. During the operation time, the temperature decreased to a range of 18 to 20°C, and the RH increased to a range of 20 to 30%. The temperature continued decreasing until the air conditioning shut off the following morning, indicating the resident wanted a lower temperature. The bedroom in residence A had the lowest temperature among the houses that were measured.

b) Residence B (Figure 17): The air conditioner in the bedroom was operated at a set point temperature of 22°C. Although the air conditioner was turned off after a short operation due to the sickness of the occupant, the room temperature rapidly decreased down to 21°C during the operation. This temperature can be said to be too low for sleeping. In the inquiry session, the resident answered that the air conditioner was usually operated the entire night until the following morning. Thus, although a desired temperature was not realized, the resident still wanted a lower temperature. Low airtightness, poor insulation, or the small size of the air conditioner may be the reason for this finding.

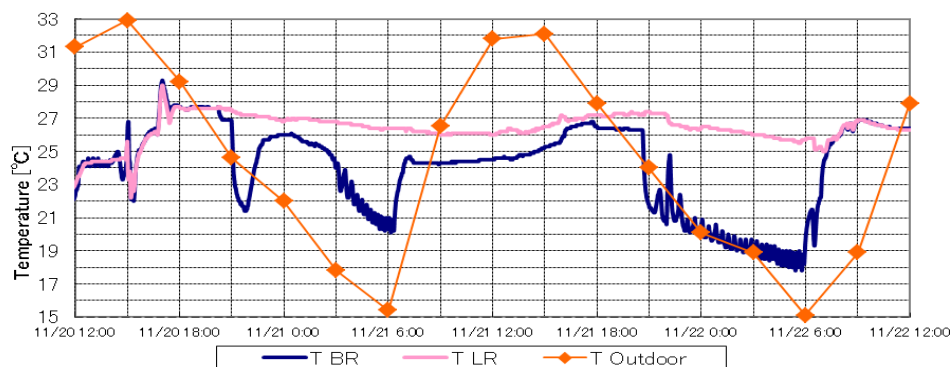


Figure 16. Living, bedroom, and outdoor temperatures (House A).

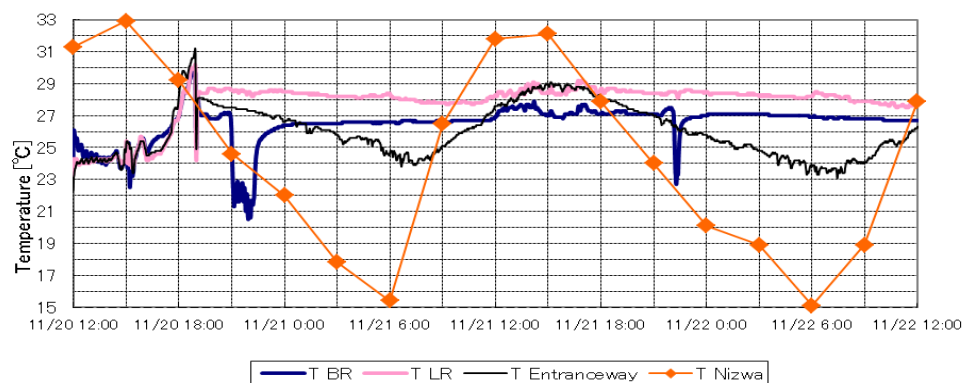


Figure 17. Living, bedroom, and outdoor temperatures (House B).

5. DISCUSSION

5.1 Comparison with Results in Kuala Lumpur and Surabaya

Figures 18 and 19 show the results for a survey that was carried out in Kuala Lumpur, Malaysia, and Surabaya, Indonesia, in hot and humid climates (Nastiti et al., 2013). These figures correspond to Figures 14 and 15 in Oman.

The number of residents who reported having a “cold” or “cool” thermal sensation and a “very comfortable” or “comfortable” comfort sensation was quite high. The percentage was 68% in Kuala Lumpur and 80 % in Surabaya. Thus, a majority of respondents felt cold and comfortable. Among people who reported being cold or cool, about 50% (Kuala Lumpur) and 25 % (Surabaya) of respondents wanted a “cooler” environment. These results qualitatively agree very well with those in the present survey in Oman. We can only find quantitative difference for respondents who chose “as it is” (neutral) in Oman.

5.2 Differences between previous study on thermal sensation and the present study

There are two forms of comfort: active and passive (Horie 1961; Kuno 1987; Nagano 1997). “Active comfort” refers to an active and vibrant condition (a desire for development), while passive comfort refers to a physiologically easy condition (a desire for deficiency).

Dear et al. (1990, 1991) carried out an experiment in Singapore to calculate a neutral temperature based on the subjects’ reporting of thermal sensations. The neutral temperature was 28.5°C. On the other hand, in an experiment where the subjects chose a favorable temperature, the neutral temperature (or comfort temperature) was 25.6°C. The reason for the three-degree difference in the two experiments seems to be accounted for by the different definitions of comfort involved. That is, the neutral temperature in the second experiment was based on active comfort, while the neutral temperature in the first experiment was based on passive comfort. In the second experiment, the subjects seem to have chosen cold and comfortable temperatures on the basis of active comfort.

Figure 20 shows the percentage of people who feel uncomfortable at each thermal sensation in Kuala Lumpur plus Surabaya, and Nizwa plus Rustak. At the cold, cool, and neutral sensations, the percentage of people who feel uncomfortable is very low in contrast with rather high percentages at the warm sensation. Although a definite conclusion is difficult since the total number of the respondents declaring warm or hot thermal sensations is very small, the profile from cool to warm sensations seems asymmetric, which indicates that the respondents in this survey tend to prefer a cold environment.

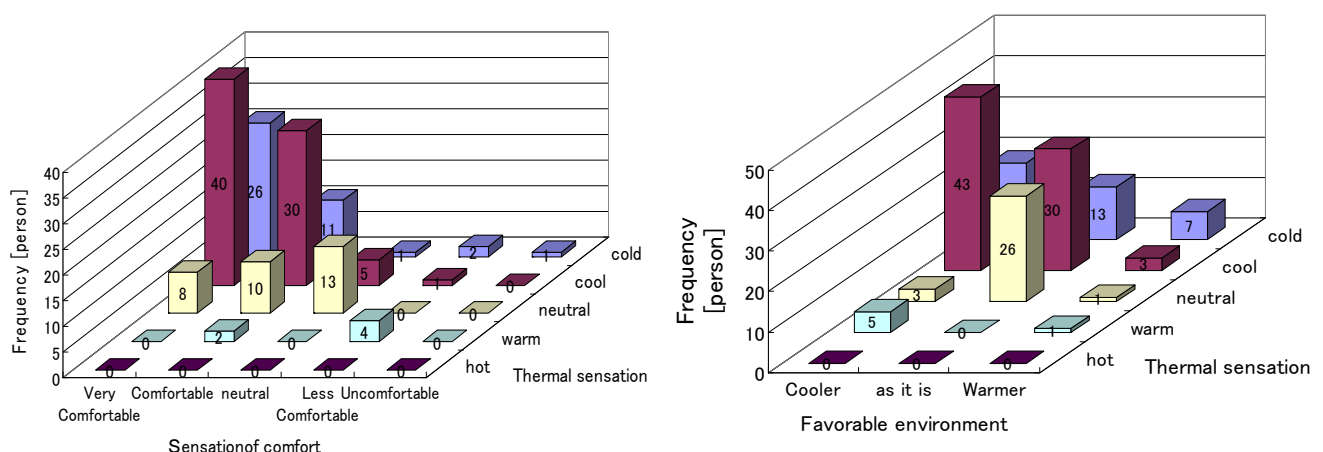


Figure 18. Breakdown of sensation of comfort and favorable environment in each thermal sensation (Kuala Lumpur)

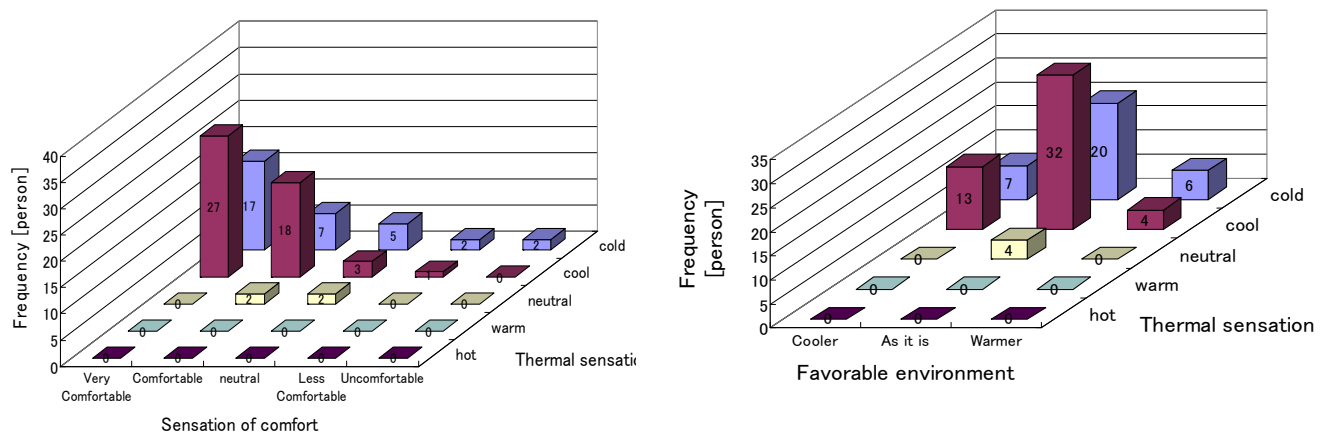


Figure 19. Breakdown of sensation of comfort and favorable environment in each thermal sensation (Surabaya)

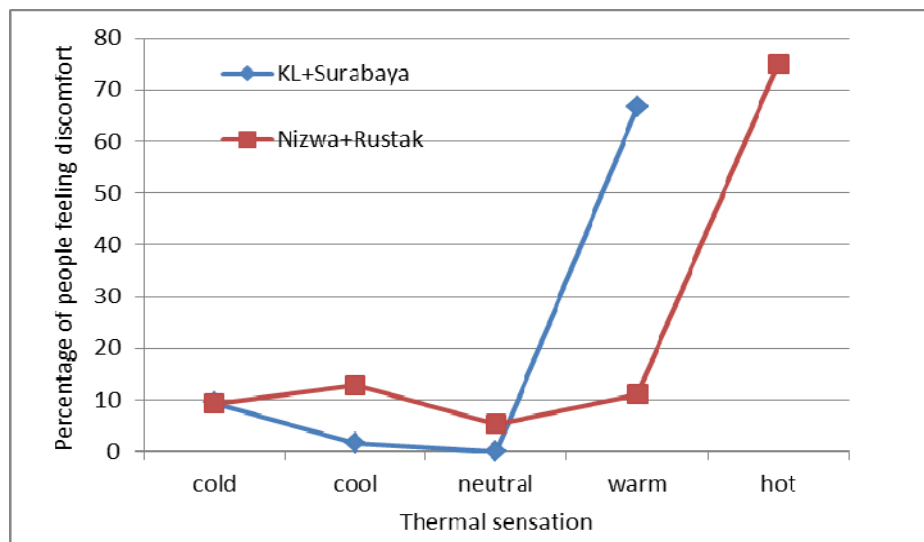


Figure 20. Percentage of people feeling uncomfortable at each thermal sensation

CONCLUSION

A questionnaire survey was conducted in Nizwa and Rustak, Oman, both of which have hot, dry climates. The purpose of this study was to identify the indoor thermal conditions created by using air conditioners in residential buildings in which residents have the opportunity to choose the temperature setting in their bedroom.

In both cities, the mean operating time reported by respondents was longer than 9 hours. The respondents reported selecting a low temperature setting while sleeping, despite the fact that many of them reported that they were cold while sleeping. Many respondents reported various health problems.

The results of a subjective assessment of indoor thermal environments and correlations between thermal and comfort sensations indicate that many people consider cold environments to be comfortable and tend to prefer cooler environments. These results are very similar to those found in hot and humid climates such as those of Indonesia and Malaysia.

ACKNOWLEDGMENTS

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APPENDIX: QUESTIONNAIRE FOR RESIDENTS

Details are omitted in some questions.

■ About your home.

Q. 1 Your family: Please fill in your and your family members' ages and sexes in the following table.

Q. 2 Type of house

Q. 3 Number of stories

Q. 4 Structure of house

Q. 5 Electrical appliances: What kinds of electrical appliances do you have other than an air conditioner? Please fill in the number of units.

TV (), PC (), refrigerator (), washing machine (), rice cooker (), microwave oven (),

fixed-line phone (), vacuum cleaner (), electric fan ()

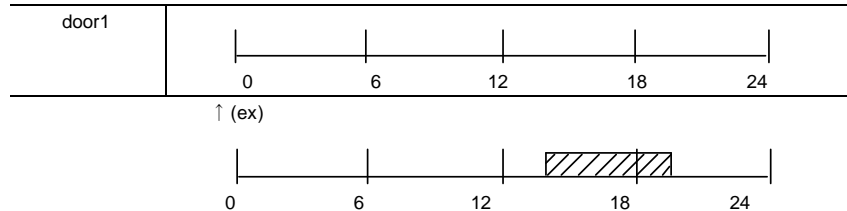
Q. 6 Plan of house

Q. 7 Address and map

Q. 8 Users of the bedroom

Q. 9 Opening and closing of windows for ventilation: Please fill in the times when you open the doors and windows for ventilation. Please use the numbers from Q. 6 to identify doors and windows.

【living room】



Q. 10 Electricity charge: How much is your electricity bill every month?

User	Yourself • Father • Mother • Older sister/brother Younger sister/brother • Servant • Relative
Set-point temperature	() °C
Thermal sensation	Cold • cool (slightly cold) • neutral • warm (slightly hot) • hot
Comfort sensation	Very comfortable • slightly comfortable • neutral • Slightly uncomfortable • very uncomfortable
More favorable environment	Cooler • as it is • warmer

Q. 11 Clothing during sleep: What kind of clothes do you and your family members wear while sleeping?

Q. 12 Annual income: If you don't mind, please choose the total annual income of your family.

■ Use of air conditioners.

Q. 13 Manufacturer and price

Q. 14 Usage time of air conditioner(s): When do you use the air conditioner?

Q. 15 Set-point temperature of air conditioner: Please fill in what temperature the air conditioner is set to, along with the comfort level when using it at this set-point temperature.

Q. 16 Health: Has there been any change in your health or physical condition since beginning to use the air conditioner? If so, please fill it in.

ADDITIONAL QUESTIONNAIRE

Q. 1 Do you feel that you need an air conditioner in your daily life?

Q. 2 View concerning air conditioners: What is your opinion of air conditioners?

Q. 3 Are you conscious of the economic effects of using an air conditioner?

Q. 4 Thermal environment in bedroom with air conditioner: Please choose the most appropriate description of the thermal environment in the bedroom during normal use of an air conditioner.

【Bedroom 1】

User	Yourself • Father • Mother • Older sister/brother Younger sister/brother • Servant • Relative
Set-point temperature	() °C
Thermal sensation	Cold • cool (slightly cold) • neutral • warm (slightly hot) • hot
Comfort sensation	Very comfortable • slightly comfortable • neutral • slightly uncomfortable • very uncomfortable
More favorable environment	Cooler • as it is • warmer

Q. 5 Countermeasures when cold (or slightly cold) in the bedroom: What are the countermeasures that you take to address coldness when using the air conditioner in the bedroom? Please circle all that apply.

【Bedroom 1】

User	Yourself • Father • Mother • Older sister/brother Younger sister/brother • Servant • Relative
1	Raise the set-point temperature of air conditioner
2	Wear a jacket
3	Wrap myself in a blanket
4	Open the windows to introduce air
5	Shut down the air conditioner
6	Do nothing because I like a cold environment
7	Endure the cold environment
8	Have never felt cold
9	Other ()

Q. 6 Electricity use: How do you feel about electricity use?